

Using a Community of Intelligent Synthetic Entities to Support Operational Team Training

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Keywords:

Synthetic teammates, Synthetic Battlespace, Human Behavioral Representation, HLA, Federation, Team Training, Naval Aviation, E-2C

ABSTRACT: *A strong need exists for a simulation-based means to provide individuals in deployed settings teamwork and cross-platform coordination skills training in realistic, mission-oriented scenarios. This need can be met by using advanced human behavioral representation technology to provide synthetic teammates and collateral entities operating within a sophisticated synthetic battlespace. When combined with a full range of automated, intelligent agent-based instructional support capabilities including real-time performance measurement, diagnosis and feedback along with menu-driven scenario generation and replay capability for debriefing purposes the result is a system called Synthetic Cognition for Operational Team Training (SCOTT). An initial SCOTT system is being developed to provide training in cross-platform coordination skills for members of the Navy E-2C Hawkeye tactical crew. The architecture and behavioral representation issues in E-2C SCOTT are discussed.*

1. Introduction

A common requirement in naval aviation operations is for a team of operators to work together efficiently and effectively to attain coordinated mission success. Unfortunately, insufficient resources are available to ensure that aviators receive the practice and feedback required for them to maintain their team skills in deployed environments. The cause is twofold: first, technologies and methodologies needed for deployed team training are inadequate. Second, such training resources as instructors, ranges, and ordnance are lacking, particularly in the deployed environment. Therefore, the development and demonstration of a theoretically sound means to training advanced team skills—one that will allow aviators to practice in the absence of trained instructors or team members—is crucially needed.

The Synthetic Cognition for Operational Team Training (SCOTT) project, sponsored by the Office of Naval Research, is a response to this need. SCOTT is an effort to apply advanced human behavioral representation methods to meet a critical team training need in the Navy, specifically to provide deployable training for critical aviation team skills without requiring any additional personnel besides the individual receiving the training.

SCOTT will allow aviators to practice in the absence of trained instructors or live teammates through the use of:

- synthetic teammates and adversaries in a synthetic battlespace,
- synthetic instructors to provide performance assessment, measurement, feedback, and training management.

The synthetic teammates pose a unique challenge in SCOTT because they must engage the trainee in realistic teamwork behaviors in a believable manner. Not only does this require them to carry out reasoning needed to generate collaborative and teamwork behaviors but, in the Naval aviation context, it also requires them to carry out the majority of these behaviors verbally.

The key issues being addressed in SCOTT are detailed below. In Section 2, the training issues involved in cross-platform aviation team training are discussed along with a brief description of the operational context for which SCOTT is being developed. Next, the SCOTT approach to developing synthetic teammates is presented, with particular attention to the issues of developing a synthetic teammate that can provide both teamwork practice opportunities and tutoring/instruction. Finally,

Report Documentation Page

*Form Approved
OMB No. 0704-0188*

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1. REPORT DATE 2001	2. REPORT TYPE N/A	3. DATES COVERED -						
4. TITLE AND SUBTITLE Using a Community of Intelligent Synthetic Entities to Support Operational Team Training								
5a. CONTRACT NUMBER 								
5b. GRANT NUMBER 								
5c. PROGRAM ELEMENT NUMBER 								
6. AUTHOR(S) 								
5d. PROJECT NUMBER 								
5e. TASK NUMBER 								
5f. WORK UNIT NUMBER 								
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) CHI Systems, Inc. 716 N. Bethlehem Pike Lower Gwynedd, PA 19002								
8. PERFORMING ORGANIZATION REPORT NUMBER 								
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) 								
10. SPONSOR/MONITOR'S ACRONYM(S) 								
11. SPONSOR/MONITOR'S REPORT NUMBER(S) 								
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited								
13. SUPPLEMENTARY NOTES The original document contains color images.								
14. ABSTRACT 								
15. SUBJECT TERMS 								
16. SECURITY CLASSIFICATION OF: <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 33%; text-align: center;">a. REPORT unclassified</td> <td style="width: 33%; text-align: center;">b. ABSTRACT unclassified</td> <td style="width: 34%; text-align: center;">c. THIS PAGE unclassified</td> </tr> </table>			a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified	17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 9	19a. NAME OF RESPONSIBLE PERSON
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the SCOTT architecture and component details are presented.

2. The Aviation Cross-Platform Team Training Problem

Currently, fleet aviation units lack advanced team skills training opportunities, although it has been widely acknowledged that advanced team skills are crucial to the safe and effective operation of Naval aviation assets. For example, poor team skills contributed to more than 80% of 370 Navy/Marine Corps aviation mishaps that were attributable to human error [1]. Hartel et al. reported situation awareness problems contributed to 60% of the incidents, and decision making errors contributed to 50% of the incidents. As a result, the Navy research community's interest has increased for developing advanced training methods, tools, and strategies to enhance team skills [2].

Recently, researchers have identified two significant challenges associated with team training:

- a) team skills training needs to be mission and context specific [3]; and
- b) complex cognitive skills and team process behaviors are highly perishable; therefore, frequent refresher training on advanced team and decision making skills is required [3].

Such training challenges are of particular relevance for deployed aviation crews. It is likely that team skills required to perform a given operational mission are deficient due to lack of recent practice, or lack of practice under mission specific parameters. Training is needed in deployed environments to provide aircrews with an opportunity to refresh team skills related to the type of mission that the crew is about to perform, the type of enemy about to be encountered, and the type of terrain to be involved.

The need for effective, comprehensive organic training becomes increasingly crucial as the Navy moves toward operations in littoral contexts where practicing skills in an aircraft are impossible due to political and security issues. Furthermore, fleet personnel do not have access to the necessary training resources while deployed. Shore-based training technologies and strategies are both space and personnel prohibitive for shipboard and forward deployed units. Moreover, while the need for practice-based team training increases, the realities of optimized manning suggest that there will be fewer deployed training supervisors in the future, as well as few opportunities to engage multiple platforms and personnel in live exercises requiring intelligent tutoring training technology. The need to control costs will further limit the opportunity for live exercise-based team training. The average annual training cost per student across the services exceeded \$72,500 in FY95 [4]. Additionally, the costs associated with live exercises and training events (such as Fleet

Exercises and Air Wing Detachments to NSWC) involves millions of dollars across the turn around training cycle.

Thus, a way had to be found that provides team training, particularly in areas of cross-platform coordination, while using minimal manpower and making minimal demands on such operational resources as fuel, ranges, and ordnance. The SCOTT solution entails:

- *synthetic battlespaces* (eliminating the need for use of live systems) based on constructive simulations, in which a single human trainee can interact with
- *synthetic teammates*, based on cognitive modeling and human behavioral representation technology, and in which the instruction is provided by
- *intelligent tutoring* system technologies, including use of instructional agents for real-time assessment, diagnosis, and feedback.

While the synthetic battlespace technology has rapidly matured in recent years, the latter two components of SCOTT represent major challenges. The technology for creating believable synthetic human behavioral representations is still emerging, and the aviation teamwork environment, as discussed below, poses a challenging case. In addition, while intelligent tutoring has matured rapidly in recent years its primary focus has been on individual- skills and knowledge training, and based on direct interactions between the trainee and the simulation environment. The expansion to team training, in which interactions among human team members are part of the diagnostic space, as well as human-computer interactions, represents a significant expansion of the existing state of the art.

2.1 The Operational Context

Before discussing the technology issues, it is useful to briefly review the operational context for which SCOTT is being developed. The program is focusing on cross-platform coordination for carrier-based naval aviation, primarily on the E-2C Hawkeye aircraft. Analogous to the Air Force E-3 AWACS, the Hawkeye provides a variety of airborne command, control, communications and intelligence functions for Naval missions. The tactical crew of the E-2C consists of a CICO (Combat Information Center Officer), ACO (Air Control Officer), and RO (Radar Officer), in addition to the pilot and co-pilot. The tactical crew must interact with other airborne platforms, including tactical aircraft (e.g., FA-18, F-14), electronics aircraft (e.g., EA-6B, EP-3), tankers (e.g., KC-135), and other command and control aircraft (e.g., AWACS), as well as surface platforms involved in air space management (e.g., the Combat Information Center-CIC on Aegis ships in the battlegroup). Ideally, SCOTT would eventually provide tools for developing synthetic teammates for all on-platform team members (ACO, CICO, RO), as well as off-platform friendly airborne and surface entities. This would allow any member of the E-2C aircrew to train in working across this complete space of coordinating platforms.

In the initial development cycle reported here, the focus is explicitly on providing a training capability for the ACO. The primary synthetic teammate or synther [5] being implemented in this development cycle is a CICO. The CICO synther must be able to perform the command and control tasks of the CICO in the context of strike warfare mission scenarios. These functions are complex, including perceptual processing of displayed sensor data, situation assessment, reasoning and decision making for appropriate courses of action, determining the information requirements of other entities engaged in the mission, executing control actions, and communicating information to teammates at appropriate times. These issues are discussed in more detail below.

An initial scenario and demonstration will feature a constrained battlespace to include E-2C tactical crew interactions with various aircraft in a strike mission. Of particular concern is including intelligent tactical aircraft (e.g., F-18, F-14) simulations that will allow the ACO trainee and the CICO synther to interact in complex and non-scripted interactions in the battlespace. The specific scenario being used is a large scale, medium range, strike mission conducted by carrier airwing assets that are controlled by a Navy E-2C Hawkeye crew. This strike is executed in conjunction with joint assets against a well defended target located deep inside a fictitious county.

The joint strike package involved in this scenario is divided into four categories based on mission function: Sweep, Attached TARCAP, Strikers and Support Units. The Sweep units are the fighter aircraft that fly out ahead of the strike package addressing airborne threats through the ingress route, target area and egress route. The Attached TARCAP units are fighter aircraft assigned to provide close escort for the strike aircraft. The Striker units are the aircraft that are tasked with delivering bombs on target. The Support units are the aircraft that perform all of the required support duties for the main strike package units. Specific support functions include strike and fighter control, suppression of enemy air defense (SEAD), electronic surveillance, and various intelligence units, delousing of returning aircraft and tanking.

In addition to controlling the large scale strike mission, the E-2C crew is also required to check-in and coordinate the handoff of close air support (CAS) assets to be employed in the Marine Amphibious Operating Area (AOA). Individual E-2C crewmember mission responsibilities are designed to most efficiently support the various strike elements and warfare commander needs. The ACO is assigned the fighter control duties in support of the Sweep package. The ACO communicates directly with the Air Warfare Commander (AW) as required. Additionally, the ACO is the primary manager of the Hawkeye's electronic surveillance (ES) equipment. The Radar Officer (RO) is assigned the duties of fighter control for the Attached TARCAP assets in addition to general situation awareness (SA) calls for strike aircraft. The RO ensures optimum performance of the E-2C weapon system. In addition to ensuring proper data link

operation, the CICO oversees all aspects of the strike mission to ensure complete mission success. The CICO coordinates with external units for most strike support issues and will ensure that the various warfare commanders are kept apprised of the current tactical situation as required. Virtually all of these activities are carried out through voice communications (both within the E-2C and with other aircraft), and interactions with the E-2C crewstations.

3. SCOTT System Architecture

The SCOTT system is designed to be part of an intelligent guided practice process [6], in which practice-based training is only one part of a larger continuous training cycle. Each iteration of the cycle prepares for, conducts, and analyzes a single simulated problem-solving scenario, in which the trainee interacts with a realistic environment. The cycle begins with the specification of training objectives that are selected from pre-defined inventories of job knowledge and skills and a database on the individual's past performance and training. These objectives are then used to select (or if necessary, generate) a problem scenario that will require the use of the targeted knowledge, skills, and tasks. As the problem scenario is run, pre-defined performance measures are applied to trainee actions, and used to drive the diagnosis of trainee performance in terms of the stated objectives. This diagnosis process drives both the generation of real-(and near-real-) time instruction and feedback to the trainee, and assessment of trainee improvement and needs for future training. The training architecture is divided into three parts. The main part is the practice scenario execution, in which the trainee performs a simulated mission in a synthetic battlespace. The second part is the training management component, which sets up and initializes the problem scenario based on the individual's training needs. Once the simulated mission is completed, the third part comes into play. This is the performance assessment and After Action Review (AAR) component, which performs a detailed analysis of trainee performance during the scenario (using the predefined measures) and provides automated assessment, instructional feedback, and builds a detailed AAR report.

The overall architecture of the Version 1 SCOTT System is shown in Figure 1. The practice scenario execution portion of the system is implemented as an HLA federation, consisting of a battlespace simulation based on JSAF and TacAir Soar, and an E-2C federate being developed under SCOTT. This organization allows additional federates to be added later (e.g., an AEGIS ship). The training management component is shown on the upper left of Figure 1, and the performance assessment component in the lower left. Each is briefly discussed below.

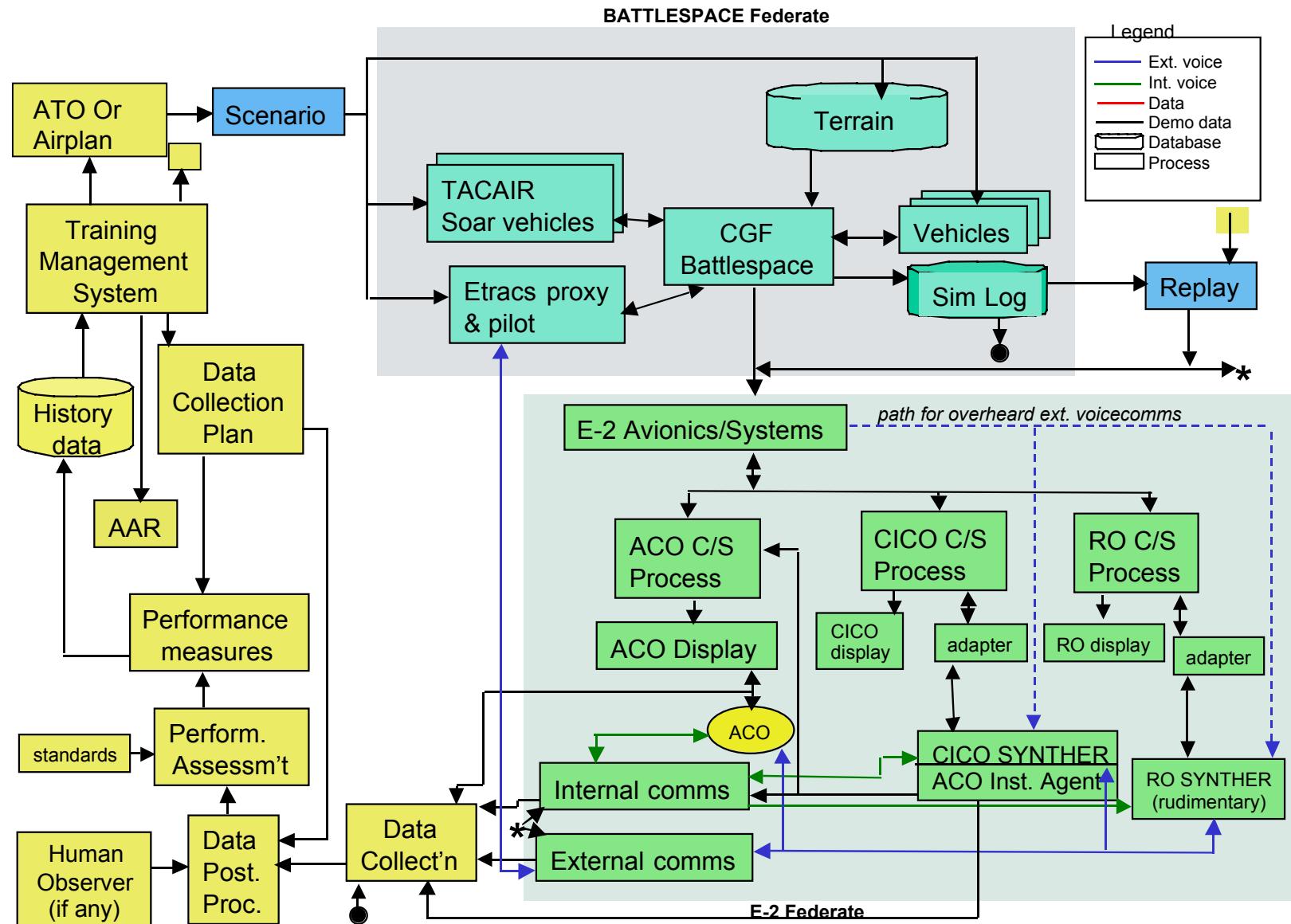


Figure 1. SCOTT Architecture

3.1 Battlespace Federates

The battlespace federates simulate a synthetic theater of war using the Joint SAF (JSAF) simulation software [7]. The E-2C federate, which simulates the aircraft and its pilot, is derived from an E-2C JSAF entity, augmented with a simulation of the internal crewstations and crew. Other aircraft in the scenario are also simulated as JSAF entities, primarily those that are not involved in direct interactions with the E-2C tactical crew. Those vehicles that do interact directly with the E-2C tactical crew are simulated as intelligent air platforms, based on the TacAir Soar technology [8]. The intelligent air platforms communicate with other elements within JSAF using standard JSAF communications protocols, with one exception – voice communications with human trainee(s) and synthetic teammates in the E-2C federate. These communications are not supported by either JSAF or HLA protocols, and are therefore handled through a separate voice communication network. The network supports three functions:

- 1) recognition of speech from a human trainee in the E-2C (federate) and translation to a digital representation understandable to the TacAir Soar synthetic pilot;
- 2) generation of synthetic speech from a TacAir Soar synthetic pilot over the voice network; and
- 3) communication of text-based message content between TacAir Soar synthetic pilots, and iGEN-based synthetic teammates onboard the E-2C.

See [9] for additional details on the issues involved in voice interactions among human and synthetic entities in a distributed constructive simulation.

3.2 E-2C Federate

The E-2C federate represents the tactical crew of the E-2C aircraft within the synthetic battlespace. Within this federate, each tactical crewmember (ACO, CICO, RO) may be either a human trainee or a synthetic teammate. Thus, each must interact with the battlespace in the same manner as a human Naval Flight Officer (NFO) in a real E-2C, i.e., through the tactical crewstation on-board the aircraft. In SCOTT, these tactical crewstations are emulated on desktop (i.e., Windows-based) machines, using a rehosted version of an E-2C simulator called E-TRACS [10].

The current version of SCOTT contains a full synther for the CICO position. The RO is a rudimentary synther, acting primarily as a role-player. In order for each of these two synthters to interact with the emulated crewstations, a software ‘adapter’ is provided. This adapter allows the synther access to all display contents and display dynamics, and allows the synther to manipulate all controls at the crewstation.

The information on the crewstation displays (particularly the tactical plots) are generated through an E-TRACS component that simulates the processing done by the E-

2C avionics system. It uses, as inputs, data on the battlespace that represents the data that the E-2C would receive from its sensors and data links (albeit at an unclassified level). This data is obtained, as needed, from the battlespace federates using HLA-based communications. Most interactions that the trainee/synthters have with the crewstations simply affect the way information is displayed/processed by the avionics. The crewstation interactions do not affect the battlespace. Rather, the command and control functions of the E-2C tactical crew are conducted via voice channels. As noted above, this is done using a separate voice communication network that spans the battlespace and E-2C federates.

The voice communication system uses two separate channels. One channel manages communications within the E-2C tactical crew, and the other channel manages communications between the E-2C tactical crew and external platforms. This was primarily an engineering decision, based on the fact that that external TacAir Soar intelligent entities used a different voice recognition framework than that needed by the on-platform synthters. It is important to recognize that both on-platform and off-platform communications are not just “point-to-point”. Communications by any E-2C crewmember can be overheard by any teammate. This is important to the teamwork functions on-board the aircraft and to the coordination between the E-2C and other friendly platforms, and thus to the design and functioning of the synthters.

The final component of the E-2C federate is an intelligent instructional agent software component that observes, assesses, and critiques the activities of the ACO trainee within the current context of the (simulated) mission. In some cases, it provides feedback directly to the trainee, (primarily via the voice channel), and other times it provides its assessment to the post-exercise assessment component of the system. The synthetic teammates and the instructional agent are discussed in more detail in Section 4 below.

3.3 Training Management Components

Although behavioral representation simulation issues are critical in SCOTT, the overall goal of the system is to provide a means of training. Training management within SCOTT is based on the intelligent guided practice training model discussed above. The main functions of the training management system are to:

- track trainee performance and characteristics across guided practice scenarios, and
- use that performance history to generate new practice scenarios.

In the scenario generation process, the new scenario characteristics are based on training requirements and objectives for the position and on the trainee’s prior practice results against those objectives. Thus, as a new

practice scenario is created it is associated with specific training objectives to be pursued during its execution. This, in turn, activates objective-specific performance measurement requirements which are passed to the performance measurements components, thus focusing trainee assessments on the specific objectives of the just-created training scenario. The technology used to implement this training management functionality is adapted from the training management system described in [15].

3.4 Performance Assessment Components

A key difference between a simple simulation system and a training system is the presence of performance assessment and feedback in the latter. SCOTT provides performance assessment via two different channels:

- from the instructional agent or synthetic instructor components of the synthters within the E-2C federate, and
- from a post-processing analysis of trainee behavior.

The instructional agent (discussed below) is an extension of the CICO synther that uses the synther's domain and task knowledge to provide an on-going stream of context-based observations and assessments of trainee behavior. These assessments may be diagnostic at either the behavioral level (e.g., trainee failed to provide timely calls to track 'X') or at the cognitive level (e.g., trainee does not understand procedures for 'X'), or simply context-based events. While all of the observations and assessments made by the instructional agent are stored for post-run analysis, some are used to generate real-time feedback to the trainee. In most cases, the real-time feedback is structured so as to be delivered by the CICO synther as a form of 'coaching' to the ACO trainee.

SCOTT also maintains a comprehensive data collection process to create a body of data for performance measurement post-processing. In addition to instructional agent outputs, this data repository includes all data on the behaviors of the entities in the synthetic battlespace (via the standard JSAT logging facility), plus all voice communications (reduced to textual form, as recognized or generated by the system software) internal to the E-2C and between the E-2C and other entities, plus all keyboard actions and display contents of the human ACO trainee. From this rich repository, the post-scenario performance assessment is conducted. This analysis is more exhaustive than that conducted by the instructional agent during the scenario, and it is able to engage in multi-pass analysis in a way that the real-time instructional agent can not. The assessment process is structured by data collection inputs and standards for measurement/assessment provided by the training management components based on the objectives involved. The assessment process is designed to be able to accept highly structured inputs from a human observer/instructor using a specialized interface, but this is not necessary nor is this considered the normal mode of

use of the system which is intended to be without a live instructor). The performance assessment process produces inputs to the after action review which is provided to the trainee after the analysis is completed.

4. Synthetic Teammates and Instructors

One of the primary challenges in SCOTT was the need to provide human behavioral representations – synthters -- for controlling a number of on and off-platform battlespace entities, as shown in Figure 2. These two types of entities required different engineering solutions. The off-platform entities, such as the F-14 sweep package, interact with the ACO trainee in the same way that they would in the real battlespace – via verbal interactions using specific communication networks and through digital data links. In general, however, the off-platform entities communicate with the E-2C only occasionally, and do so in a highly stylized and structured means relying on well-defined syntax, phraseology, and content. Their main focus is on piloting their vehicles and completing their portion of the air tasking order. These behaviors were already largely available in the form of intelligent pilots created through the Soar artificial intelligence technology. The TacAir Soar pilots [8] were already compatible with the JSAT battlespace, and had some ability to communicate verbally with standard command and control entities [11]. Thus, the TacAir Soar pilots could be integrated to provide the synthetic off-platform teammates, with a modest effort to expand their verbal capabilities to include the structured interactions required with the E-2C.

E-2C Combat System

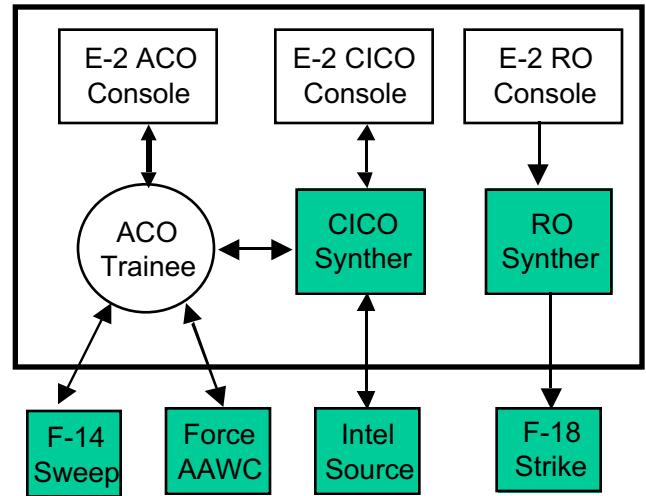


Figure 2. SCOTT Synthetic and Human Entities

The on-platform synthetic teammates, however, required a deeper and more focused understanding of the command and control domain, and a richer means of communicating within the E-2C tactical team. These on-platform teammates communicate more frequently with the ACO, using a variety of communication strategies ranging from spontaneous speech to structured communications, and

including both direct communication and understanding/processing of overhead communications. In addition, the on-platform synthetic teammates had to interact with the E-2C crewstations in a functional manner. Finally, the on-platform synthters offered an instructional opportunity, by enabling an even greater level of control over the nature and delivery of the training component of the underlying exercises. For example, the ability the synthetic teammates could be manipulated to induce errors and thus provide a training opportunity for the human trainee (e.g., provide backup and/or compensatory behaviors). For such reasons, the on-platform synthetic teammates are implemented as fully embodied cognitive models (cf., [12]). Such cognitive-model based synthetic interactive teammates have been termed “synthters” [5]. The underlying technology used to create the SCOTT synthters is the CGF-COGNET system and iGEN™ software.

The overall internal architecture of CGF-COGNET-based synthters is pictured in Figure 3. Additional details on CGF-COGNET can be found elsewhere in this volume (see [13]). The architecture pictured in Figure 3 is turned into a synthter by defining and representing the knowledge needed by each component of the cognitive system:

- perceptual knowledge, used by the perceptual process interprets visual, auditory, and linguistic cues and internalizes, in symbolic form, the information they contain,
- declarative knowledge, maintained in memory, which represents the categorical, indicative, and associational structure of the domain,
- procedural knowledge, used by the cognitive process to activate domain-based goals (through a recognitional process) and accomplish them through application of domain knowledge and use of physical instrumentalities (e.g., manipulating the crewstation, speaking to teammates),
- metacognitive knowledge, which defines the contexts by which various goals are activated, the situational priorities by which they compete for attention, and the self-awareness by which the problem-solving process is managed to account for factors such as workload, physical constraints (i.e., ears can't listen to three messages simultaneously), and interruptions; and
- motor knowledge, used by the motor system, to translate intentions for action into specific physical manipulations of the outside world

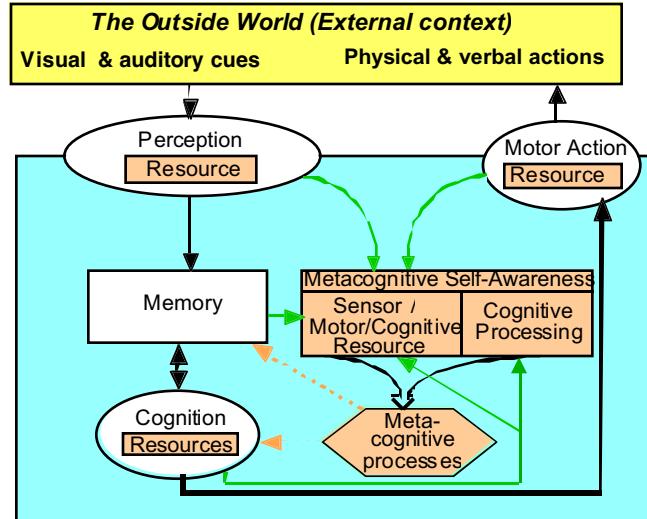


Figure 3. SYNTHER Cognitive Architecture

4.1 Domain Knowledge and Reasoning

All the on-platform synthters for SCOTT are built from a common empirical analysis, largely produced by the Fleet Integration Training and Evaluation Research (FITER) Program [14]. FITER performed detailed cognitive task analyses that focused on team shared knowledge, task strategies, and team skills used by a naval air wing at the Fallon Naval Air Station.

Several aspects of domain knowledge are common to the E-2C tactical team. First, they must mentally build and maintain a spatial and a temporal representation of radar tracks as viewed through their respective display consoles. Second, they must possess an understanding of the capabilities and limitations of weapons platforms in terms of weapon release ranges, electromagnetic signal (ES) signatures, as well as radar coverage zones and how they relate to the dynamic tactical situation in terms of identification disambiguation. Third, they must maintain constant communication with the elements of the strike package and work with them to maintain pre-planned schedules and tasking while responding to such dynamic tactical situations as pop-up SAM sites and enemy aircraft launches. A number of additional key tactical concepts from FITER analyses are incorporated into the SCOTT CICO synthter (Table 1).

Table 1. FITER Tactical Concepts

Tactical Concept	Definition
Situational awareness (SA)	“ a large scale mental representation of the tactical situation held by aircrews...”
Allowable risk	“...aircrews draw on SA to evaluate whether to prosecute an engagement, weighing mission objectives, rules of engagement, and survivability”
Flow	“...a direction of movement or apparent movement...Both friendly and threat aircraft have flow, and each influences the other...experienced aircrews establish a flow that will allow them to achieve the mission’s objectives”
Deconfliction	“...the design and maintenance of flow and direction of travel to minimize the risk of potential fratricide”
Sanctuary	“...the creation of a haven in time or space during the mission to allow an element to conduct an action without restriction”

The SCOTT synther must be able to represent the essential task work of a CICO, a great deal of which is either directly interacting with on- and off-platform team members or monitoring other team member interactions in order to maintain overall situational awareness and ensure mission success. In doing this, it combines the background knowledge and reasoning capabilities (summarized in Table 1) with more specific procedural knowledge that allows it to:

- interact with teammates by recognizing their utterances and responding verbally,
- perform the requisite task-level work of the CICO such as track ID assessment and ES correlation,
- perform critical team-level tasks such as performing compensatory behaviors and proactive information exchange, and
- ‘tutor’ the ACO trainee, providing selective diagnosis, instructional feedback, and remediation while referencing internal situational and tactical understanding.

This last capability is that of an instructional agent, above and beyond its role as synthetic teammate.

One of the most important capabilities of the CICO synther is the ability to engage in verbal interactions with its human team members – in this case, the ACO trainee. The interaction is in two forms: “hearing” the ACO trainee through the use of speech recognition subsystems and “speaking” to the ACO trainee through the use of a text-to-speech subsystem. In this manner, the CICO

synther is able to interact with the human trainees and communicate essential tactical information throughout the entire battlespace, as well as overhear equally important tactical communications.

Another important capability of the CICO synther is the ability to offer real-time verbal feedback to the ACO trainee. The feedback is based on departures from expectations generated by the CICO as part of its situational awareness about ACO-specific actions and task requirements. In the E2-C context, the CICO is responsible for overall strike mission performance and, therefore, needs to maintain SA at multiple levels of abstraction and from the perspective of various team members internal and external to the E-2C platform. It is precisely because of the central role that the CICO plays in the E2-C that much of the instructional context for monitoring the ACO trainee has been derived from the perspective of the CICO.

5. Conclusions

SCOTT is being implemented and demonstrated at the Synthetic Forces laboratory at the Naval Air Warfare Center Training System Division, Orlando, FL. In addition to the E-2C SCOTT, an inter-domain validation of the SCOTT architecture is being undertaken by applying the same approach to the operating environment of the Virtual Environment Landing Craft Air Cushion (VE-LCAC). The goal of the VE-LCAC effort is to develop a prototype training system capability that allows any LCAC crewmember (craft master, navigator, or engineer) to train in real time with synthetic crewmembers. The planned extension of the SCOTT architecture in the VE-LCAC domain will culminate with a human-in-the-loop demonstration of the testbed/prototype training system in which a simulated crewmember participates in the execution of an amphibious assault mission scenario. Extension of the SCOTT architecture into a virtual testbed environment will confirm the robustness of the approach in meeting training requirements and supporting optimized manpower in different development frameworks and training application areas.

6. Acknowledgements

In addition to the authors, SCOTT is being developed by a team consisting of Dr. Jerry Owens, Dr. Kelly Neville, Lee Napravnik, William Weiland, Dan Scolaro, Jackie Scolaro, Brian Glucroft, and Kevin Bracken of CHI Systems; Jeff Miller of MicroAnalysis and Design; Dr. Jared Freeman and Dr. Daniel Serfaty of Aptima; Milt Stretton and Dr. John Burns of Sonalysts; Dr. Jennifer Fowlkes of the University of Central Florida; Ronnie Soles and Tony Buscemi of the Naval Air Warfare Center Training Systems Division; and Dr. Harold Hawkins of the Office of Naval Research. The SCOTT program is sponsored and funded by Office of Naval Research.

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